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**Respirator Studies for the
ERDA Division of Safety, Standards, and Compliance**

July 1, 1975—June 30, 1976

by

T. O. Davis

P. B. Raven*

C. L. Shafer, M.D.

A. C. Linnebur, M.D.**

J. M. Bustos

L. D. Wheat

D. D. Douglas, Section Leader

*Consultant, Professor, Institute for Aerobics Research, 11811 Preston Rd.,
Dallas, TX 75320.

**Consultant, Los Alamos Medical Center, Los Alamos, NM 87544.

**los alamos
scientific laboratory**

of the University of California

LOS ALAMOS, NEW MEXICO 87545

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RESPIRATOR STUDIES FOR THE
ERDA DIVISION OF SAFETY, STANDARDS, AND COMPLIANCE

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- I. PHYSIOLOGIC STUDY - T. O. Davis, P. B. Raven,
C. L. Shafer, A. C. Linnebur, J. M. Bustos,
L. D. Wheat

A. Introduction

In 1974 the Energy Research and Development Administration (ERDA) Division of Safety, Standards, and Compliance (DSSC) saw the need to obtain data on the physiological effect on the wearer of a respirator, for criteria for future standards. Discussions between ERDA DSSC and The Los Alamos Scientific Laboratory (LASL) Respirator Research and Development Section (RRDS) defined the primary goals as determining what effect wearing a respirator had on worker performance, and which physiological parameters an industrial physician should consider when examining an employee who will be wearing a respirator while working.

As a result of these discussions, ERDA DSSC funded LASL RRDS during FY 1976, for a physiological study of the effect of wearing a respirator.

B. Review of Literature

A literature review showed that while quite a bit of work had been done in this area, the majority was in two categories; general and overly specific. The general articles dealt with the effect of general physiological parameters, for example, inspiratory and expiratory resistances.^{1,2} The specific articles dealt with a single parameter for a single device, for example, inspired air temperature for closed-circuit self-contained breathing

apparatus (SCBA),^{3,4} or with a single device for a specific industry.⁵ Both types of articles helped us in planning for testing, however they did not supply what was needed for ERDA DSSC work.

The literature review also showed that fire fighters were recognized as having a higher-than-normal incidence of cardiovascular and pulmonary diseases, believed to stem from their occupation.⁶⁻¹⁰

C. FY 1976 Study Goals

Discussions between ERDA DSSC and LASL ERDS had defined overall needs and goals, as described in Section I.A. SCBA's are widely used by ERDA contractors and general industry. Fire fighters in general, and ERDA fire fighters in particular, use heavy SCBA respirators in the course of duty. The literature review had shown that fire fighters have a higher than normal incidence of cardiovascular and pulmonary diseases. Therefore, the first study would look at this type of respirator.

The type of respirator most widely used by fire fighters is an open-circuit SCBA. The most common model is a Scott 30-min unit, with a regulator which can be operated in either demand or pressure-demand mode, and with a facepiece with a pressure-loaded exhalation valve. This was the device used during testing (see also Section I.D.4).

During FY 1976, LASL completed a pilot study on the effect of wearing an open-circuit SCBA. The pilot study covered varying workloads, effect of the weight of the unit alone, effects of demand and pressure-demand operation, heat build-up inside the facepiece, and differentiated the subjects into smokers and non-smokers.

D. Research Methods

1. Subjects. Fifteen subjects were chosen from 22 volunteers. The subjects were ERDA fire fighters, and tests were conducted during duty hours. Of the 15 subjects, 8 were non-smokers and 7 were smokers. Each subject was given a complete physical examination including blood and urine analysis, chest X ray, and resting ECG. After passing the physical, each subject was given a Bruce maximal stress test¹¹ to determine his fitness for the experimental testing. Only healthy individuals were chosen as subjects. Each subject:

- a. read and signed informed consent form, Appendix A.
- b. had a 0.5-h instruction and practice session, learning to walk and run on a treadmill, before the maximal test.
- c. had two 0.5-h practice sessions, learning to walk and run on a treadmill while wearing an SCBA before starting the experimental testing.

For all tests the subject reported dressed in shorts and tennis shoes, having fasted from food and drink for 5 h, and following 8 hr of sleep.

Seven of the 27 volunteers were not used as test subjects for the following reasons:

Two dropped out of the study for personal reasons,

Two could not endure maximal performance on the treadmill due to minor orthopedic problems,

Three had abnormal results during the Bruce screening test and were referred to their private physicians.

2. Experimental Method. Each subject was tested four times; without respirator weight or facepiece as a control situation (condition 1); with respirator weight but no facepiece (condition 2); with weight and facepiece, demand mode (condition 3); and with weight and facepiece, pressure-demand mode (condition 4). All tests were performed at the same location, under similar environmental conditions, and at approximately the same time of day. Repeated measures and random-order presentation of conditions were used during the test.

The subjects were tested on a treadmill, using the standard Bruce Protocol. A physician monitored the ECG signals during testing and recovery. A five-lead ECG monitoring system was used to monitor positions I, II, AVF, AVL, V_4 .¹² Although the chest position normally monitored is V_5 , the backpack harness straps dislodged the V_5 electrode, so a V_4 position was used. Blood pressure (left arm) was monitored using a standard pressure cuff and stethoscope. Forehead temperature (T_{fore}) was monitored with a thermistor thermometer (Yellow-Springs), see Fig. 1.

Immediately after the treadmill stress test each subject was evaluated during a 5-min, seated, recovery period. Respirator apparatus worn during testing was also worn through the recovery period. A blood sample was drawn at 4 min into the recovery period to determine the blood lactate level.

3. Techniques of Measurement. A Quinton treadmill capable of speed from zero to 400 m/min at grades of zero to 25% was used for the test. Prior to the test the subject was seated in a chair for a 5-min rest period. Resting blood pressure, heart rate, and multilead electrocardiograms were obtained following the rest period. The subject then stood and started walking on the treadmill. The elevation and speed changes, called stages, used during the test are shown in Fig. 2.

Each test was terminated when the subject could no longer be motivated to continue, or if any significant abnormalities occurred in ECG, or blood pressure, or on the decision of the attending physician. A 5-min seated recovery period followed the test during which heart rate, forehead temperature, and blood pressure were monitored. Differences in heart rate, blood pressure, T_{fore} , and test duration time were used as a prediction of aerobic capacity, i.e., $\dot{V}O_2$ max.¹³ Appropriate corrections were made for

Fig. 1.
Test leads attached to test subject.

- Represents the time of blood pressure, heart rate, multilead ECG and forehead temperature determinations.

Fig. 2.
Schematic of Bruce Treadmill Test Protocol.

the decreased barometric pressure at Los Alamos (Elevation-2200 m; barometric pressure = 585 mm Hg).¹⁴

Electrocardiogram monitoring and multilead recording were obtained using an Avionics cardio-scanner and cardio-chartter. The heart rate and ECG waveform were constantly monitored and intermittently recorded. Significant waveform changes were analyzed at the time by the attending physician and "post hoc" by the LASL consulting cardiologist. Blood pressure determinations were obtained by indirect brachial auscultation using the Riva-Rocci method and the fourth sound was used to define diastolic pressure since during moderately heavy exercise the fourth and fifth sounds are distinctly separate. Systolic index (heart rate and systolic pressure) was also calculated as an index of myocardial oxygen cost. The 4-min post-exercise blood sample was analyzed for lactate level by enzymatic analysis¹⁵ and used for determining the overall degree of physical stress.

4. Test Respirator. The respirator used was a Scott Air-Pak, an open-circuit self-contained breathing apparatus (SCBA), with a full face mask, see Fig 3. The units used were Bureau-of-Mines approved. The standard facepiece, regulator, high-pressure hose, and compressed air tank were used. The Scott backpack was not used because the straps interfered with chest electrodes. A Survivair backpack and harness were used, which did not interfere with chest electrodes. The regulator was mounted on the tank. Two 36-cm (14.2-in.) low-pressure hoses were joined to make a hose long enough to connect the tank-mounted regulator to the facepiece. A calibrated thermistor thermometer was used to monitor the temperature of the inhaled air (T_{insp}), in a copper tee installed at the joint of the low-pressure hoses, see Fig. 4. The facepiece used the pressure-loaded exhalation valve for all

Fig. 3.
Subject wearing test respirator, front view.

Fig. 4.
Subject wearing test respirator, side view, while on treadmill.

tests because ERDA fire fighters are, in general, supplied with the pressure-loaded exhalation valve and a regulator which is switch-selectable for demand or pressure-demand mode. The pressure-loaded exhalation valve causes a lower exhalation resistance pressure in demand mode than in pressure-demand mode. The total weight of the test unit was 15.820 kg (34.9 lbs) with a charged (13.8 MPa) bottle. The difference in weight between charged and discharged (4.1 MPa) bottles was 0.895 kg (1.97 lbs). Compressed air used to fill the bottles met grade E standards.¹⁶ The decrease in pressure in the tank which occurred during use caused the temperature of the air in the tank to decrease, and, therefore to decrease the temperature of the inspired air (see II. E., Results).

LASL RRDS realized that the modifications made the test respirator an unapproved [by Mine Enforcement Safety Administration - National Institute of Occupational Safety and Health, (MESA-NIOSH)] device. However, the purpose of the study was to gain basic data on the physiologic response to wearing this class of device, and the individuals were not being exposed to contaminants. Therefore, the use of an approved devices was not necessary.

5. Statistics. The extent to which the respirator conditions (a) affected work duration and the cardiovascular system for both smokers and non-smokers (b) was determined using a two-factor factorial analysis of variance (a X b) with repeated measures across respirator conditions. When a significant F interaction was found, differences within simple main effects were probed by a Newman-Keuls post-hoc test to determine where significant ($P < 0.05$) differences between means existed.¹⁷ In addition, differences between the smoker and non-smoker clinical screening data were analyzed using a student t statistic.

E. Results

Table I gives some pertinent characteristics of the two groups of subjects. There was no significant difference in age, height, weight, or measured pulmonary parameters between smokers and non-smokers. Hence, differences observed in the results are not related to major structural differences of the two groups.

Table II is a summary of the data obtained. Total time on the treadmill was, statistically, significantly greater during test condition 1 (control, no weight, no facepiece) than for any of the other three experimental conditions for both smokers and non-smokers, see Fig 5. In addition, non-smokers performed on the treadmill for a longer period of time than the smokers. At the second and third stages of the treadmill protocol, the heart rate of the non-smokers was significantly less during test condition 1 than during any other condition. This difference was not found for the smokers. The final stages of the treadmill protocol showed no significant effect on heart rate or blood pressure for any test condition. Hence, calculated systolic index (systolic pressure X heart rate) also was non-significant.

TABLE I

SUBJECT CHARACTERISTICS
(Means $\pm$ Standard error of the means)

		Age (yrs)	Ht (cm)	Wt (kg)	FVC (l)	FEV _{1.0} (%)
Nonsmokers $\bar{x}$		31.0	176.6	75.9	5.13	84.0
(N=8) $SE_{\bar{x}}$		2.0	3.9	3.7	0.3	2.3
Smokers $\bar{x}$		30.3	173.1	71.7	4.90	83.1
(N=7) $SE_{\bar{x}}$		2.2	2.6	4.9	0.31	3.5
t		0.26	0.78	1.00	0.568	0.22
P		NS	NS	NS	NS	NS

With the exception of T_{fore} and T_I there were no further significant differences observed across conditions. Figure 6 presents the response of forehead temperature to progressive work and recovery of both groups of subjects. T_{fore} was significantly lower during conditions 3 and 4 than during conditions 1 and 2 for both smokers and non-smokers. There were no differences in T_{fore} between conditions 3 and 4, although the mean trend of condition 4 was always lower than condition 3; see Fig 6. These responses are related to the progressively decreasing inspired air temperature observed throughout the test; see Fig 6. Inspired air temperatures decreased an average of 9.7°C , with a standard deviation of 2.4°C , during the demand and pressure-demand breathing conditions and this resulted in an average decrease of 2.5°C , with a standard deviation of 1.8°C , in the measured T_{fore} . The inspired air temperature dropped due to the continually decreasing pressure in the air tank.

The electrocardiographic recordings evidenced no remarkable findings, although minor alterations in patterns were observed during the course of the test. There were only four instances where a series of premature ventricular contractions (PVC's) were observed and these appeared to be unrelated to conditions or to smoking habits. See Table III. A summary of the subjective comments offered by each subject at the end of each test is outlined in Table IV and proves more informative with respect to the effect of the respirator. In both conditions 1 and 2, leg pains and general fatigue accounted for all the reasons for stopping. However, in those conditions where the face mask was being worn (3 and 4) other complaints were lack of air, claustrophobia, and excessive heat, in addition to leg pain and general fatigue.

TABLE II

AVERAGE GROUP DATA FOR EACH TREADMILL STAGE, MAXIMAL WORK
AND RECOVERY DURING WORK UNDER THE FOUR RESPIRATOR CONDITIONS

		CONDITIONS							
		<u>1</u>		<u>2</u>		<u>3</u>		<u>4</u>	
		<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>
Stage One (10%, 1.7 mph) 2'30 - 3'00	HR (beats/min)	105.8	104.4	110.6	108.8	112.6	110.5	117.4	110.8
	SBP (mm Hg)	134.7	138.8	129.5	139.5	132.6	137.5	13.5	146.1
	MBP (mm Hg)	99.4	100.8	93.1	102.1	95.9	99.2	97.0	105.6
	T _{INSP} (°C)	—	—	—	—	19.2	18.0	18.4	18.1
	T _{FORE} (°C)	33.1	33.7	33.2	33.4	32.7	31.2	31.7	31.7
	SI (10 ³)	14.2	14.5	14.3	15.2	14.9	15.2	15.8	16.2
Stage Two (12%, 2.5 mph) 5'30 - 6'00	HR (beats/min)	131.0	121.9	139.0	133.3	142.4	138.5	150.9	137.3
	SBP (mm Hg)	150.3	149.8	140.9	157.5	150.7	158.1	161.4	162.9
	MBP (mm Hg)	105.1	104.6	99.6	107.6	106.3	109.6	108.3	112.1
	T _{INSP} (°C)	—	—	—	—	16.1	15.2	15.3	15.4
	T _{FORE} (°C)	33.1	33.6	33.1	33.2	32.2	30.6	31.6	31.2
	SI (10 ³)	19.7	18.3	19.6	21.0	21.5	21.9	24.4	22.4
Stage Three (14%, 3.4 mph) 8'30 - 9'00	HR (beats/min)	171.0	160.8	179.3	174.6	177.2°	174.9 ⁺	181.4°	175.9
	SBP (mm Hg)	165.6	163.5	162.0	172.2	162.2*	177.6 ⁺	171.0*	176.0
	MBP (mm Hg)	110.8	113.0	110.7	114.9	110.2*	118.8*	113.5*	118.2
	T _{INSP} (°C)	—	—	—	—	11.9°	11.6 ⁺	11.1*	11.5
	T _{FORE} (°C)	33.0	33.7	32.9	33.5	31.2*	29.0 ⁺	30.5*	30.1
	SI (10 ³)	28.3	26.3	29.0	30.1	28.7*	31.1 ⁺	31.0°	31.0
Maximum Values	TIME (sec)	711.7	746.6	586.7	615.6	571.0	589.6	575.9	612.5
	HR (beats/min)	190.8	189.1	185.8	185.4	185.1	180.8	188.7	184.0
	SBP (mm Hg)	176.6	171.5	163.7	172.8	161.9	177.9	169.9	177.0
	MBP (mm Hg)	100.8	102.1	99.3	105.6	99.4	96.0	95.9	97.0
	T _{INSP} (°C)	—	—	—	—	11.1	10.1	9.9	9.7
	T _{FORE} (°C)	32.8	34.0	32.7	33.6	27.7	29.2	29.9	29.2
	SI (10 ³)	33.7	32.4	30.4	32.0	30.0	32.2	32.1	32.6
		*N = 7	*N = 6	°N = 5					

TABLE II (continued)

Recovery Data

		<u>CONDITIONS</u>							
		<u>1</u>		<u>2</u>		<u>3</u>		<u>4</u>	
		<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>	<u>S</u>	<u>NS</u>
Recovery min 1	HR (beats/min)	163.7	168.4	164.7	166.9	170.8	163.3	169.7	167.6
	SBP (mm Hg)	168.9	160.9	149.7	160.9	165.1	167.5	174.7	169.9
	MBP (mm Hg)	112.9	110.6	95.1	106.8	109.1	114.1	109.6	116.8
	T _{INSP} (°C)	—	—	—	—	10.9	10.3	9.8	9.6
	T _{FORE} (°C)	32.9	34.1	32.6	33.9	30.4	29.5	29.5	29.5
	SI (10 ³)	27.6	27.1	24.7	26.9	28.2	27.4	29.6	28.5
Recovery min 3	HR (beats/min)	132.4	134.3	133.4	131.9	132.3	129.3	132.8	133.4
	SBP (mm Hg)	155.4	156.5	145.1	156.6	153.0	160.9	157.7	162.4
	MBP (mm Hg)	106.1	107.0	100.9	104.8	108.7	112.6	107.6	114.9
	T _I (°C)	—	—	—	—	12.0	11.4	11.0	10.9
	T _{FORE} (°C)	33.4	34.5	32.6	34.1	31.2	30.6	30.3	30.7
	SI (10 ³)	20.6	21.0	19.4	20.7	20.2	20.8	20.9	21.7
	Lactate (mg/cm ³)	78.0	68.5	68.4	74.0	60.8	60.6	61.5	71.9
Recovery min 5	HR (beats/min)	119.3	117.9	118.3	121.6	120.6	114.9	121.3	121.1
	SBP (mm Hg)	132.3	136.4	124.7	135.0	133.6	136.5	125.4	139.5
	MBP (mm Hg)	92.1	97.4	91.9	96.1	99.7	101.6	93.6	101.3
	T _I (°C)	—	—	—	—	12.8	12.3	11.7	11.7
	T _{FORE} (°C)	33.6	34.5	32.9	34.2	32.0	31.3	31.9	31.2
	SI (10 ³)	15.8	15.8	14.8	16.4	16.1	15.7	15.2	16.9

F. Discussion

It is evident from the data that wearing the SCBA apparatus significantly reduced the total time on the treadmill (maximal work performance) of the fire fighters. The reductions were 17.5%, 21%, and 18.5% for conditions 2, 3, and 4, respectively, regardless of smoking habits. Surprisingly, there were no significant decrements in performance due to the breathing mode utilized (condition 3 or 4) while wearing the mask, although the wearing of the mask resulted in a far greater degree of subjective discomfort. Obviously, work performance was primarily related to the weight of the SCBA. Decreases in work performance have previously been reported^{18,19} and, in agreement with our findings,

Fig. 5.
 Total time on treadmill vs. test condition for all subjects.

have related the decrement to the additional weight of the firefighting equipment.

Investigations into simple air-purifying respirators have documented significant decrements in maximal work performance regardless of the physical fitness of the subjects.^{20,21} As this type of respirator adds minimal loads to the subject, it was concluded that increased respiratory burden was the primary cause of a decreased maximal work performance. However, in an extensive investigation of four types of air purifying respirators during submaximal performance (10 min work at 50% of maximal work capacity) Chatterjee²² was unable to observe any significant change in heart rate response due to the wearing of the masks. This lack of effect may be related to the low work loads being used which resulted in a minimal increase in respiratory work. During the present study, non-smokers had lower heart rates during non-weight-bearing conditions (condition 1) than during conditions 2, 3, and 4 at both the 2nd and 3rd stages of the Bruce treadmill test. However, wearing the mask did not affect the heart rate during exercise. Yet, the inclusion of subjective responses concerning the mask implicates the increased respiratory burden as one reason for decreased work performance. Although not statistically significant, the mean decrement in performance and the greatest number of complaints concerning air supply were observed during condition 3, or when the subjects were using

Fig. 6.
Forehead and air temperatures vs. time. $\bar{x}_n$ is the average for n subjects.

demand mode. These complaints were not apparent during pressure-demand mode even though the number of claustrophobic responses were the same for both conditions. Hence, it could be implied that the increase in respiratory work (respiring against an added inspired resistance) was a factor in the decreased work performance. Recently, this has been subjected to a careful investigation utilizing subjective and objective analysis of various combinations of inspired and expired resistance.² It was

TABLE III

ELECTROCARDIOGRAPHIC FINDINGS FOR ALL
CONDITIONS AND BOTH GROUPS OF SUBJECTS*

		<u>Conditions</u>				
		<u>ECG Comments</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Nonsmokers (N=8)	[	Junctional S - T segment - depression	5	4	3	2
		Increase in S - Wave depth	1	-	1	-
		PVC	-	1	-	1
		Increase in P - Wave amplitude	-	-	1	-
Smokers (N=7)	[	Junctional S - T segment - depression	3	5	3	3
		Increase in S - Wave depth	1	-	1	-
		PVC	1	1	-	-

*The number in each block represents the number of changes within each condition for a specific group of subjects. e.g. 5 nonsmokers out of 8 had Junctional S - T segment - depression

TABLE IV

SUBJECTIVE COMMENTS REPORTED AS
REASONS FOR TERMINATION OF EXERCISE

		<u>Conditions</u>			
<u>Comments</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	
Leg Pain	11	14	8	7	
General Fatigue	4	1	2	4	
Lack of Air	—	—	8	—	
Claustrophobia	—	—	4	4	
Hot Mask	—	—	1	1	
Expired Resistance High	—	—	—	1	
Dry Throat	—	—	—	1	
Total	15	15	23	18	

found that subject discomfort was minimal when the pressure across the apparatus was less than 17 cm H₂O and the expiratory resistance was very low. However, it was further observed that excessive resistance exerted during inspiration was a major factor in determining subjective tolerance. Unfortunately, our data do not allow us to conclude that inspired resistance was too high during inspiration on demand mode even though subjectively the demand mode provided the most discomfort.

It may be postulated from the subjective responses that the performance of the demand valve is a factor of discomfort and physical limitation to the wearer during heavy work. Government regulations²³ only require the valve to be able to deliver 200 liter/min flow and, while the manufacturers have generally supplied valves capable of delivering 400 - 450 liter/min flow, it has been observed that peak respiratory flow rates during maximal work may exceed 720 liter/min. Therefore, part of the explanation of mask limitation during hard work may be related to the inability of the regulator valve to supply sufficient air within a given respiratory cycle. This needs further investigation.

In the present study a significant surface cooling effect was observed during the wearing of the face mask. It was also noted that as the work load increased the inspired ventilation volumes increased, and consequently, the T_I decreased. As the inspired air is circulated within the mask, the cooler air, a maximum of 19°C cooler than T_{Fore} , caused a 2.5°C drop in T_{Fore} . This cooling effect is beneficial to the SCBA wearer as it helps to remove excess heat generated by the increase in metabolic rate. More

importantly, it has been previously shown during thermal stress that when T_{INSP} is greater than core temperature the capability to perform work is significantly reduced.^{3,24-26} One of the major findings in previous evaluations of four types of SCBA apparatus for mine rescue work was that the apparatus that provided lowest T_{INSP} provided greater tolerance to work in heat and also improved subject comfort.²⁴ Hence, the SCBA used in this study would be of benefit to a fire fighter exposed to high-heat loads during heavy work.

One further comment concerning the operation of the Scott-Air Pak SCBA needs to be made. The apparatus used in the investigation when fully charged to 13.8 MPa is rated as providing sufficient air for 30 min of operation. Yet following 10 min of treadmill walking to maximal levels and a subsequent 5 min of recovery, the air remaining registered 4.1 MPa, enough for a further 5 min of operation. In many cases firemen are required to work at high workloads for long periods of time,⁹ 15 min or more, and under these conditions, the 30-minute tanks may not provide a sufficient amount of air. The practice of using only 15-min air tanks for both economy and weight reduction purposes may prove fatal to the fire fighter. However, regardless of speculations, it would appear that it is imperative that the weight of the apparatus be reduced to a level whereby the maximal efficiency of the operator is not reduced, and that in situations of high work load, sufficient amounts of air be made available for more than 15 min. Also, we feel that a serious limitation exists with respect to the regulator valve and that there is a need for further evaluation of the valve during high work loads.

G. Recommendations

We recommend that a physiological study evaluate the effects of wearing an open-circuit SCBA during strenuous exercise, concentrating on pulmonary parameters. Such a study should incorporate bench tests of available regulators to determine air flow characteristics. The two phases of testing should be compared in order to determine whether available regulators deliver adequate air flow rates to the wearer at all times. Manufacturers of this type of device should be invited to observe and participate in such a study to insure their acceptance of the results. ERDA may want to set performance standards from the results of such a study.

While not a goal of this project, the literature review and our own findings indicate that fire fighters as a group have a higher-than-normal incidence of cardiovascular disease.⁶⁻¹⁰ We recommend that ERDA consider including maximal stress tests in ERDA fire-fighter annual physicals. Further, ERDA should consider sponsoring physical conditioning programs during working hours for fire fighters.

One comment from a subject was that participating in the FY 1976 study, during which he had to reach maximal exertion and then recover while wearing the respirator, gave him a great deal more confidence in the device than regular training had provided. We

recommend that SCBA training programs include having the trainee strenuously exercise and recover while wearing the device.

The subjects all commented that the Survivair harness used in the study was more comfortable and allowed more movement than the Scott harness. Also, modifications were made to the Survivair harness fasteners which, if the wearer were incapable of removing the device, allowed another man to remove the device from the wearer in a matter of seconds. Because of the increased acceptance and safety of the developed harness, we recommend continued work between LASL RRDS and the ERDA Los Alamos Fire Department to compare the developed harness with existing harnesses.

ACKNOWLEDGMENTS

The authors would like to thank the following people for their help on this study:

D. Hahn, Assistant Fire Chief, and H. Richardson and S. Gonzales, Platoon Chiefs, for their constant assistance in setting-up and scheduling the testing portion of this project.

The nurses and lab technicians who supported the testing portion of the project with dedication and superior quality work.

The fire fighter volunteers who, for science, went through difficult physical testing and maintained high interest and enthusiasm.

II. TRAINING VIDEO TAPES - by T. O. Davis

LASL RRDS produced one training video tape for DSSC during FY 1976. The title of the tape is "Operation and Use of Air Purifying Respirators as Protection Against Airborne Radioactive Materials". The tape was made by Sandia Laboratories Video Services Division. The tape is in color, broadcast quality, and professionally narrated. A copy of the tape, and a typed copy of the video tape narration, with notes, was delivered to the ERDA coordinator in January 1976.

III. DSSC RESPIRATOR MANUAL - by D. D. Douglas

In FY 1975, plans were made to provide DSSC with a Respirator Manual which could be used to assist ERDA contractors in complying with ERDA regulations concerning the use of respirators. This was necessary for two reasons; ERDA contractors are among the largest users of respirators in the United States, and the existing regulations are contained in generalized form in the American National Standards Institute (ANSI) document "Practices for Respiratory Protection," ANSI Z88.2. The initial draft for ERDA's

manual was completed during 1975, and extensive editing was done during FY 1976. In FY 1976 the manual was published as report LA-6370-M.

ANSI Z88.2 provides basic information on respiratory protection, however, it is difficult to determine application of these standards to specific situations. The DSSC respirator manual provides basic policy information concerning the use of respirators. It stresses the necessary ingredients for an acceptable respiratory protection program and discusses, in detail, how to meet the various required elements of a respirator protection program. It discusses why respirators are acceptable for some hazards and not acceptable for others. The respirator user is warned that a complete understanding of the airborne concentrations of toxic materials within the work-place and their relationship to permissible levels^{27,28} is necessary.

Complete discussions of the advantages and disadvantages of various respirator types which may be used are given. Such information is not included in ANSI Z88.2. Information is also included on the NIOSH Respirator Approval System, since ERDA now requires the use of NIOSH-approved respiratory equipment unless special circumstances dictate otherwise. The respirator selection guide given in Z88.2 is expanded to include respirator Protection Factors (PFs). The use of PFs, which have been developed at LASL over the past few years, is explained. In this regard, detailed information is given concerning the establishment of a quantitative man-testing program to enable ERDA contractors to utilize a quantitative fitting program. Methods of fitting respirators on the job are detailed and the methods necessary to maintain a proper respiratory protection program are spelled out.

IV. LASL RESPIRATOR ADVISORY COMMITTEE - by D. D. Douglas

The LASL Respirator Advisory Committee was formed at the request of ERDA, DSSC, to review special respiratory protective problems which are unique to ERDA contractors and may require the use of equipment that is not approved by the NIOSH Testing Certification Branch (TCB). The committee is composed of persons with outstanding qualifications in the area of respiratory protection. (See Appendix B).

The committee met once this year to consider the testing of the Savannah River Suit, which is an airline suit that the DuPont Savannah River Project uses. The committee reviewed the LASL RRDS test report and determined it would not be advisable to approve this suit for the following reasons:

1. The hose used for the Savannah River Suit was not sufficiently strong to withstand the pressure test required.
2. The suit could achieve a PF of over 10 000 only if a variety of precautionary measurements were taken. The committee felt the precautionary measurements were too elaborate to be diligently followed by all employees.

3. The committee did not know the PF required for this application of supplied air suits. The committee asked that in the future, work site information be presented along with the suit test report so that they could determine whether the suit was adequate for the task.

The committee charter was reviewed by ERDA Headquarters, who determined that the charter was more elaborate than necessary. It was revised. A copy of the revision is included in Appendix C. The document simplifies the committee duties and is more understandable.

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APPENDIX A

UNIVERSITY OF CALIFORNIA CONSENT TO ACT AS HUMAN SUBJECT (Regular Form No. 2)

SUBJECT'S NAME: _____. DATE: _____

1. I hereby authorize _____ C. L. Shafer, M.D. _____ and

_____ Thomas Davis _____ (principal investigators) and such

assistants as may be designated by them to perform upon _____

_____ (subject) treadmill stress testing

which shall consist of the following:

As a prospective test subject I understand that I will undergo a thorough medical screening procedure prior to any experimental sessions. This screening examination requires a medical questionnaire, along with a personal interview and physical examination conducted by a physician, urinalysis, blood tests, chest x-ray, clinical lung function tests and a resting 12-lead electrocardiogram. If my general health is found to be good, and if the resting 12-lead ECG is within normal limits, I will then undergo a volitional maximal exercise stress test on a motor driven treadmill. The period of physical exertion during the actual stress test usually requires about 10 minutes. Multilead electrocardiographic tracings, heart rate, systolic and diastolic blood pressure, forehead skin temperature will be obtained immediately prior to the stress test and at each progressive stage of work (three minute intervals) throughout the

actual stress test. A V₅ ECG will be monitored continuously on an oscilloscope and recorded for 10 seconds at each minute of the test on paper tape. Only if I am still found to be in good general health and free of evidence of disorders of the heart, lungs and blood vessels - both before and after exercise - will I be accepted into the subject pool.

Following acceptance to the program I will undergo one or more practice sessions thought necessary for me to become accustomed to wearing the respirator while walking or running on the treadmill. After these practice sessions I will participate in three experimental exposure conditions. Each exposure condition will be separated by one week or more. The conditions require that I carry out the exact same stress test protocol as described above while wearing the Scott Air Pak respirator, with and without face mask and during demand and forced pressure breathing. (The respirators used in this study are those usually worn by fire fighters during fire fighting procedures. As the subject pool consists mainly of firemen the respirator should not prove to be disturbing to the subject, especially following the practice sessions.)

I will report by appointment for the experimental sessions:

a) At the same time of day following a minimum of five hours without food and drink, and twelve hours without smoking.

b) I will be dressed in T-shirt, shorts and supporter, socks and tennis shoes.

c) As heat dissipation is a factor in this study I will dress in the same clothes for each test.

d) At three to four minutes following each stress test, a three milliliter recovery venous blood sample will be taken via vena puncture from my antecubital vein.

2. The foregoing procedure(s) and/or investigation(s) has (have) been explained to me by

C. L. Shafer, M.D. and Thomas Davis
Name

3. I further understand and have had explained to me by C. L. Shafer, M.D.

and Thomas Davis that the following discomforts and risks may be involved in the stress testing procedure, such as: general fatigue, leg fatigue, leg pains or cramps, shortness of breath, sweating, nausea, fainting, chest pain, adverse blood pressure or heart rate response, development of heart rhythm irregularity or disturbance, development of abnormal ECG response and, finally, the remote possibility of sustaining a heart attack during or immediately following the procedure.

4. I understand that the potential benefits of the procedure are as follows:

a) This study is believed to be beneficial in that a physiological and clinical determination of the respirator imposed stress on a human will be evaluated.

b) There will be an explanation to me, the test subject, of my complete examination and all of my tests and the conclusions that will be reached therefrom, i.e., a scientific assessment of my physiological working capacity and a critical appraisal of my cardiac, pulmonary and circulatory functions.

5. I understand that C. L. Shafer, M.D. and
Thomas Davis (principal investigators)

and such assistants as may be selected by them will answer any inquiries that I may have at any time concerning the procedure.

6. Finally, I understand that I may terminate my participation in this study at any time, and that owing to the scientific nature of the study, the principal investigators named herein may in their absolute discretion terminate my participation at any time. I further understand that my records will be held in strict confidence from non-medical people (such as employer, insurance agents, etc.) until my additional consent or the consent of legal representative of myself or my estate is obtained to release such information unless such information includes any unusual physiological symptoms or findings that might endanger my life and health in connection with my employment. In the event I am placed in such a position, the principal investigators named herein shall, by virtue of my signature hereto, have my consent to release said information to my employer and personal physician for evaluation by them.

7. By signature hereto I acknowledge that I have read and had fully explained to me by C. L. Shafer, M.D. and Thomas Davis

and that I fully understand all of the above, including the risks and benefits to me associated with the treadmill exercise test, both without and incorporated with the wearing of the respirator in the three experimental exposure conditions.

Subject

Witness

Date

APPENDIX B

LCS ALAMOS RESPIRATOR ADVISORY COMMITTEE

Jerrold L. Caplan, Health Physicist
Occupational Health Standards Branch
Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Darrel D. Douglas, Section Leader
Respirator Research and
Development Section
Industrial Hygiene Group, MS 986
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico 87544

Edwin C. Hyatt
Industrial Hygiene Consultant
545 Rover Boulevard, White Rock
Los Alamos, New Mexico 87544

Edwin J. Kloos
Respiratory Protective Devices Officer
Mining Enforcement and Safety
Administration
U.S. Department of Interior
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Joseph Lipera, Group Leader
Industrial Hygiene & Toxicology Group
Hazards Control Department, L-519
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, California 94550

John P. O'Neill, Senior Scientist
Office of Health Standards Development
Occupational Safety and Health
Administration
U.S. Department of Labor
Washington, DC 20210

Walter E. Ruch
Regional Program Director, Region X
National Institute for Occupational
Safety & Health
U.S. Department of Health, Education,
and Welfare
1321 Second Avenue
Seattle, Washington 98010

Robert H. Schutz, Director
Test & Certification Laboratory
NIOSH ACOSH
U.S. Department of Health, Education,
and Welfare
944 Chestnut Ridge Road
Morgantown, West Virginia 26505

Charles J. Shoemaker, Director
Respirator Section, Physical
Protection Laboratory
Defense Systems Command
U.S. Department of the Army
Edgewood Arsenal, Maryland 21010

John M. White, Health Physicist
General Services Division
Chalk River Nuclear Laboratory
Atomic Energy of Canada, Limited
Chalk River, Ontario
Canada

APPENDIX C

LOS ALAMOS SCIENTIFIC LABORATORY RESPIRATOR ADVISORY COMMITTEE RESPONSIBILITIES, ORGANIZATION, PROCEDURES

I. SCOPE

A. The purpose of the Los Alamos Scientific Laboratory (LASL) Respirator Advisory Committee is to review, evaluate, formulate conclusions, and make recommendations concerning (1) the adequacy of test procedures and test criteria for respiratory protective equipment needed by Energy Research and Development Administration (ERDA) contractors, (2) the adequacy of the performance of respiratory protective equipment needed by ERDA contractors, and (3) other activities as requested by ERDA, Division of Operational Safety, Health Protection Branch.

B. The LASL Respirator Advisory Committee will advise the LASL Industrial Hygiene Group, Respirator Research and Development Section, which, in turn, will make recommendations to the ERDA Division of Operational Safety, Health Protection Branch (OS) which will make all final decisions.

II. COMMITTEE MEMBERSHIP

The committee membership shall be selected from persons knowledgeable in the field of respiratory protective equipment. A balance of members from federal agencies, industry, consultants, labor, etc., should be selected. Committee size shall be determined by OS. The Chairman and the Secretary shall be from the Respirator Research and Development Section and OS, respectively. These members shall be nonvoting members of the committee.

III. APPOINTMENTS TO COMMITTEE MEMBERSHIP

A. Appointments to membership on the committee are made by the Chairman with the concurrence of OS.

B. Each committee member will be appointed for a period of three years with reappointments possible for a maximum of one additional period of three years for a maximum period of committee membership of six consecutive years. If a committee member resigns or if he fails to attend two consecutive meetings, a new committee member will be appointed to replace this person.

IV. SPECIFIC RESPONSIBILITIES

A. Chairman

1. Makes arrangements for meetings of the Respiratory Advisory Committee, prepares agenda for meetings, and keeps members of committee informed of these plans.

2. Notifies committee members of dates and locations for meetings at least 30 days before the meeting date.

3. Directs the proceedings at committee meetings.

4. Solicits views of committee members, determines consensus of committee members on said subjects, and consolidates consensus recommendations made by committee members into an advisory report to the Respirator Research and Development Section.

B. Secretary

1. Keeps records of meetings of Respirator Advisory Committee.
2. Distributes copies of minutes of committee meetings to all committee members.

C. Committee Members

Review, evaluate, and make conclusions and recommendations relative to:

1. the responsibilities, organization, and procedures of the Respirator Advisory Committee;
2. procedures to be utilized in testing the performance of special respiratory protective equipment needed by ERDA contractors, and the performance criteria for said equipment;
3. the performance of special respiratory protective equipment needed by ERDA contractors.

V. OPERATING PROCEDURES

A. A quorum for a meeting of the Respirator Advisory Committee shall be five of the voting members of the committee.

B. Conclusions and recommendations made at a committee meeting or made by written communications between committee members and the Chairman must be agreed to by four of the voting members.

C. Review and Evaluation of Respiratory Protective Equipment

Interpretations of eligibility for testing shall be submitted directly to OS.

1. The Respirator Research and Development Section shall perform the necessary equipment tests according to procedures established by the committee and shall compare the test results with test criteria established by the committee. The Respirator Research and Development Section shall formulate conclusions and recommendations relative to the adequacy of the performance of the equipment, shall write a report containing test data, conclusions, and recommendations and shall forward copies of the report to the Chairman, Secretary, and members of the committee.
2. The committee shall study the report, review and evaluate the test results given in the report, shall formulate its own conclusions and recommendations relative to the adequacy of the performance of the equipment, and

shall report these conclusions and recommendations to the Respirator Research and Development Section.

3. The Respirator Research and Development Section shall forward all conclusions and recommendations, including dissenting opinions, to OS.

4. OS shall consider the conclusions and recommendations concerning the adequacy of the performance of the equipment and shall make a decision on whether or not to authorize use of the device.